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Low Cost Friction Stir Welding Of Aluminium Nanocomposite - A Review

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Abstract

This paper discusses the friction stir welding process, FSW tools and converting conventional milling as a CNC operated Milling machine suited for friction stir welding process at low cost for joining heat treatable aluminium alloys for aerospace and automobile industries. The aim of this study was to explain synthesis of rice husk ash at nano level and preparation of aluminium nanocomposite. The influence of the friction stirs welding on the size and distribution of reinforcement particles in the composite is another study. A detailed review is given on how to convert a conventional milling machine into a CNC milling machine to perform the Friction stir welding.

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*Keywords:*Friction stir welding, milling, nanocomposites, rice husk ash;

1. Introduction:

Friction stir welding (FSW) was invented in 1991 at The Welding Institute (TWI) of Cambridge, England [Thomas, W.M]. FSW is a solid-state joining technique that has grown rapidly in popularity in a wide variety of industries including the aerospace, railway, land transportation, and marine industries.Most often used on low melting point alloys such as aluminium, FSW has many advantages over fusion welding techniques. Because process temperatures remain below the melting point of the welded material there is no need for either shielding gas or filler material; low distortion and low residual stresses are inherent to the process FSW is also an energy efficient process that produces no fumes, arc flash, or spatter[Cook, G.E]. Perhaps the most significant advantage of FSW is that the technique allows for the joining of dissimilar materials or materials that are nearly impossible to fusion weld.

The FSW process includes three phenomena: heating, plastic deformation, and forging[Longhurst, W.R]. A non-consumable rotating tool, consisting of a probe and shoulder, is plunged into the materials to be joined and then traverses the joint line. Heat is generated through both friction and plastic deformation of the welded material. At

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elevated temperatures, the material plasticizes and is sheared at the front of the probe and it is rotated to the rear of the probe where it is forged together under significant shoulder pressure. The FSW process is illustrated in Figure 1. The advancing side is the region in which the traverse velocity and the tangential velocity of the rotating tool are in the same direction. The retreating side is the region in which the traverse velocity and the tangential velocity of the rotating tool are in opposite directions. This advancing or retreating phenomenon leads to different mixing characteristics within the weld seam, depending on location. These characteristics will be discussed further in the material flow section of the introduction. FSW can be performed on a variety of joint configurations, including butt joints, lap joints, and T-joints.[Mishra R.S]

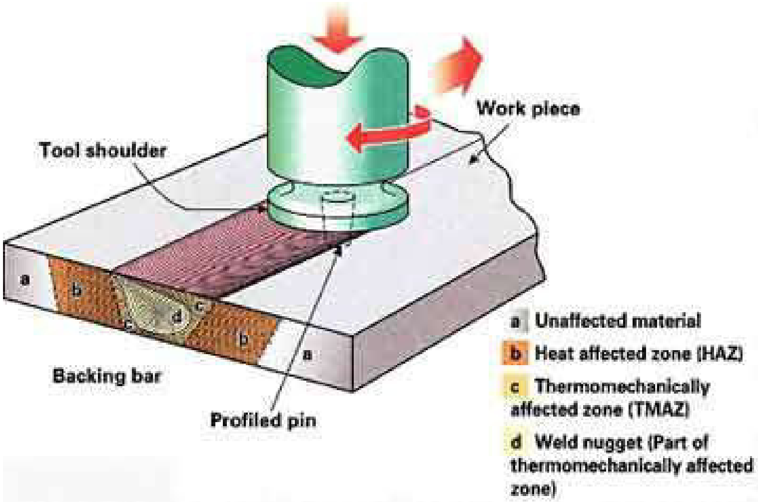

Figure-1: Friction stir welding principle and microstructure

Friction stir welding techniques have developed to a stage, in the early 21st century, where they are applied in small-scale production. FSW uses a non-consumable tool to generate frictional heat at the point of welding, inducing gross plastic deformation of the work piece, resulting into a complex mix across the joint. The plates to be joined are placed on a rigid backing plate and clamped in a manner that prevents the abutting joint faces from separating. A cylindrical-shouldered tool, with a specially projecting pin (probe) with a screw thread, is rotated and slowly plunged into the joint line. The pin length is similar to the required weld depth. The development of the FSW machine will be made possible by converting a conventional milling machine into an adequate, functional, workstation where experimental friction stir welded joints may be performed on various base materials. Friction stir welding is a solid state joining technique, which has made possible the welding of a number of materials that were previously extremely difficult to weld reliably without voids, cracking or distortion. The method was derived from conventional friction welding. [Calvin Blignault]

The shoulder of the tool is forced against the plates. The rotating tool causes friction heating of the plates which in turn lowers their mechanical strength. The threads on the pin assist in ensuring that plastically deformed material flows around the pin as the tool advances along the joint line. As the tool proceeds along the joint line, frictional heating is maintained ahead of the tool ensuring the required plastic state. It subsequently stirs and recombines the plasticized material to the side of the tool where the material cools to form a solid state weld. At the end of the weld, the tool is retracted from the plate and leaves a hole at the end of the weld.

The microstructure of a friction stir weld is unlike that of a fusion weld in that no solidification products are present and the grains in the weld region are equiaxed and highly refined. Indeed, the FSW microstructure is that of a wrought rather than a cast product.

The first attempt at classifying microstructures was made by [Threadgill P L]. His work was based solely on information available from aluminium alloys. However, it has become evident from work on other materials that the behaviour of aluminiumaluminium alloys is not typical of most metallic materials, and therefore the scheme cannot be broadened to encompass all materials. It is therefore proposed that the following revised scheme is used.

This has been developed at TWI, but has been discussed with a number of appropriate people in industry and academia, and has also been provisionally accepted by the Friction Stir Welding Licensees Association. The system divides the weld zone into distinct regions as follows:

1. 1.Weld Zone Characteristics

Figure 2&3 shows the four visually distinct micro structural zones in which welds in aluminium are typically divided into: (A) unaffected parent material, (B) heat affected zone, (C) thermo-mechanically affected zone, and (D) weld nugget. In the heat affected zone, properties and microstructure are affected by the heat from the weld, although there is no mechanical deformation. This zone retains the same grain structure as the parent materials. The thermo-mechanically affected zone shows characteristics that suggest that it underwent plastic deformation but recrystallization did not occur in this zone due to insufficient deformation strain. In weld nugget zone, intense plastic deformation and frictional heating during FSW result in recrystallized fine-grained microstructure.[Threadgill P L]

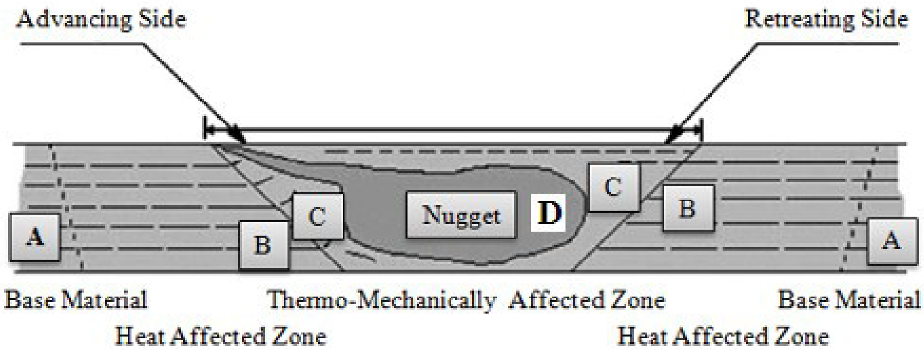

Figure-2: Schematic diagram of micro structural zones in friction stir welds in aluminium

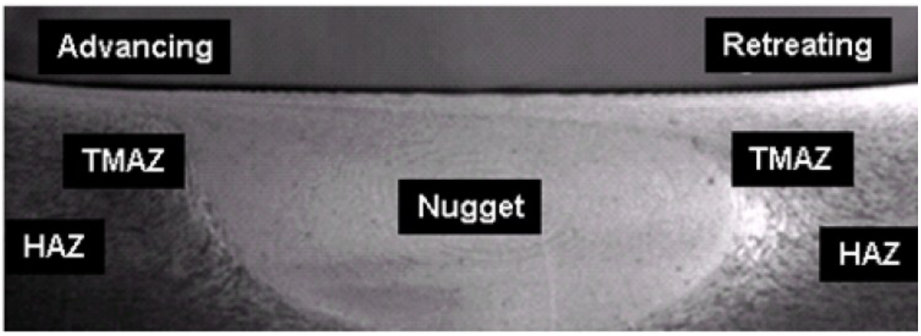

Figure 3: micrograph showing various micro-structural zones [Threadgill 1999]

Flow during friction stir welding is driven mainly by the rotation of the tool shoulder. Therefore, we develop and test an approximate analytical technique for the calculation of this flow in three dimensions, based on viscous flow of an incompressible fluid induced by a solid rotating disk. The computed velocity fields for the welding of an aluminium alloy, steel and a titanium alloy are compared with those obtained from a well tested and comprehensive numerical model. We also present an improved non-dimensional correlation to estimate the peak temperature, and an analytical method to estimate torque. The proposed correlation for the peak temperature is tested against experimental data for different weld pitch for three aluminium alloys. The computed torque values are tested against corresponding measurements for various tool rotational speeds. The hardness in the TMAZ has also been correlated with the chemical composition of aluminium alloys.

Unaffected material or parent metal: This is the material remote from the weld, which is not deformed and which, may have experienced a thermal cycle from the weld, is not affected by the heat in terms of microstructure or mechanical properties.

Heat affected zone (HAZ): The material in this region lies close to the weld center and experiences a thermal cycle used for modifying the micro structure and/ or mechanical properties. However, there is no plastic deformation occurring in this area. In the previous system, this was referred to as the "thermally affected zone". The term heat affected zone is now preferred, as this is a direct parallel with the heat affected zone in other thermal processes, and there is little justification for a separate name.

Thermo-mechanically affected zone (TMAZ): In this region, the material has been plastically deformed by the friction stir welding tool, and the heat from the process exerted some influence on the material. In the case of aluminium, it is possible to get significant plastic strain without recrystallisation and there is a distinct boundary between the recrystallised zone and the deformed zones of the TMAZ. In the earlier classification, these two sub-zones were treated as distinct microstructural regions. However, subsequent work on other materials has shown that aluminium behaves in a different manner to most other materials, in that it can be extensively deformed at high temperature without recrystallisation. In other materials, the distinct recrystallised region (the nugget) is absent, and the whole of the TMAZ appears to be recrystallised. This is certainly true of materials, pure titanium, b titanium alloys, austenitic stainless steels and coppe, which have no thermally induced phase transformation, but induce recrystallisation without strain, r. In materials such as ferritic steels and ab titanium alloys (e.g.Ti-6Al-4V), the understanding of the microstructure is made more difficult by the thermally induced phase transformation, and this can also make the HAZ/TMAZ boundary difficult to identify precisely.[Terry Khaled**]**

Weld Nugget: The recrystallised area in the TMAZ in aluminium alloys has traditionally been called the nugget. Although this term is descriptive, it is not very scientific. However, its use has become widespread, and as there is no word, which is equally simple with greater scientific merit, this term has been adopted. It has been suggested that the area immediately below the tool shoulder (which is clearly part of the TMAZ) should be given a separate category, as the grain structure is often different here. The microstructure here is determined by rubbing by the rear face of the shoulder, and the material may have cooled below its maximum. It is suggested that this area is treated as a separate sub-zone of the TMAZ.

1.1. Preparation of low cost Friction stir welding machine:

A normal conventional milling machine is modified by providing x, y and z directions by servo motors and is controlled by a CNC fanuic/simons control system. There are some preventive measures that need to be taken while updating to CNC machine. More torque will develop on spindle because of friction welding. So, high speed spindle is suitable for z axis rotation: preferably servo motor directly mounted on spindle rather than belt connection. Force has to be applied constantly on work piece. Force dynamometer has to be provided for z-axis. The heat generated during the FSW will be carried along with tool holder to the spindle. Otherwise it leads to failure of spindle bearings.

To avoid heat transfer to upwards tool chiller has to be provided to cool the spindle bearings.. 15 HP or above motor is suitable for FSW application and 2 ton and above load has to be applied by spindle along z-axis. X and y direction motors are 2HP or above servo motors, preferred to upgrade the conventional milling machine to CNC milling machine. The proposed machine is suitable for friction stir welding on aluminium nanocomposites. The temperature is measured by a temperature sensors during the friction stir welding.[Brian Travis Gibson]

1.2. Aluminium Alloys

Since the majority of work reviewed in this document pertains to aluminium alloys, it is important to discuss some of the heat treatment aspects of these alloys. A three-step sequence is used to heat treat 2xxx, 6xxx and 7xxx series and other heat treatable aluminium alloys, to higher strength levels.

Aluminium alloys are designated based on international standards. These alloys are distinguished by a four digit number which is followed by a temper designation code. The first digit corresponds to the principal alloying constituent. The second digit corresponds to variations of the initial alloy. The third and forth digits correspond to individual alloy variations. Finally the temper designation code corresponds to different strengthening techniques. Aluminium alloy reinforced with 10% vol. SiC particles with an average size of 15 microns has been joined using friction stir welding method. The joining process were carried out at rotation speed 560 rpm and linear velocity of 355 mm/min and the temperature was lower than 793 K. Microstructures of joined materials were observed according to the light and scanning electron microscopy. Changing of distribution of reinforcement particles were analysed by new RVE theory. Experimental procedurefor the tests showed the composite cast aluminium alloy matrix reinforced SiC particles with an average size 15 microns and a volume share of 10%. [Kurtyka P.]

The dynamic development of many industries was possible as a result of technical progress in the creation of new materials, new technologies for their preparation and permanent welding. One of the many problems requiring urgent solutions is to develop effective technologies permanent welding to the aluminium alloys and aluminium matrix composites. Solving this problem requires an identical strength base material and weld material, so they require unchanged the reinforcing particle size and their distribution. In the case of non-fulfillment of this condition is expected reduce mechanical properties of joints, as well as other adverse effects on the physical and chemical properties of the weld.

Research carried out on the selected composites reinforced with particles of oxides or carbides revealed that FSW process significantly affects the distribution of the reinforcing phase in the matrix material; it greatly improves [Uzun H., Amirizad M., Flores O.V.]. It also leads to fragmentation of the particles [Fernandez G.J.]. At the same time it was found that the distribution of reinforcing phase in the stir zone is uniform. This has a consequential change in mechanical and tribological properties, since the final number of particles of the reinforcing phase increases significantly and the distribution is close to isotropic. In this study it is also found that the process of a very significant impact on the structure of the matrix material affecting the separation and homogenization of the silicon needles present in the cast material [Shinoda T., Amirizad M., Storjohann D.]. The variation of transient temperature in a FSW plate of 5mm work piece thickness is observed. Based on the experimental records of transient temperature at several specific locations during the friction stir welding process for the AA 7020-T53, and comparing with the temperature measured by the thermocouples records, the results are shown from the present numerical simulation [Muhsin J. J]

Given the complexity and resource requirements of numerical models of FSW, well-tested analytical models of materials flow, peak temperatures, torque, and weld properties are needed. Here an approximate analytical technique for the calculation of three-dimensional materials flow during FSW is proposed considering the motion of incompressible fluid induced by a solid rotating disk. The accuracy of the calculations is examined for the welding of three alloys. For the estimation of peak temperatures, the accuracy of an existing dimensionless correlation is improved using a large volume of recently published data. The improved correlation is tested against experimental data for three aluminium alloys. It is shown that the torque can be calculated analytically from the yield stress using estimated peak temperatures. An approximate relation between the hardness of the thermo-mechanically affected zone and the chemical composition of the aluminium alloys is proposed.

1.3. Studies of Synthesis of nano rice hush ash (RHA)

Rice husk is unusually high in ash compared to other biomass fuels – close to 20%. The ash is 92 to 95% silica, highly porous and lightweight, with a very high external surface area. Its absorbent and insulating properties are useful to many industrial applications. RHA is a generic name describing all types of ash produced from burning rice husks. In practice, the type of ash varies considerably according to the burning technique. The silica in the ash undergoes structural transformations depending on time, temperature etc of combustion. At 550°C – 800°C amorphous ash is formed and at higher temperatures crystalline ash is formed. These types of silica have different properties and it is important to produce ash of the correct specification for the particular end use [Bronzeoak Ltd].

Fabrication and characterization of A356.2 alloy reinforced with RHA particles are dealt. The metal matrix composites (MMCs) were prepared by addition of 2, 4 and 8 wt% RHA particulates through stir casting technique. Scanning electron microscope equipped with energy dispersive X-ray analyzer is used for micro structural characterization and to identify the presence of silicon particles in the composites. Mechanical properties, density and hardness, were measured for the composites. As the percentage of RHA particles increases, the density of the composites decreases and slight increase in the hardness also was observed [Siva Prasad D.].

Figure-4: Rice husk dump and ash

2. Preparation of Rice husk nanoparticles

Rice husk is of the major agricultural by product during paddy processing. It is washed with NAOH and dried for a day to reduce the moisture content totally. The treated Rice Husk, kept in the stainless steel bowl, is burnt in the electrical furnace. The material is kept for 5hrs at a temperature of 900^{o}C.

Figure-5: Rice husk ash;

Raw Rice husk is taken for burning and produced ash in a similar manner as above. A ball mill cylindrical device (Model: Retsch, PM 100, Germany) used for grinding is shown in Figure-7.

Ball mills partially filled with the RHA and the grinding medium rotate around a horizontal axis. Different materials including stainless steel balls are used as media. Spherical balls of stainless steel are inserted into the cylindrical bowl for machining

Figure-6:High Energy Planetary Ball mill used for milling the husk

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In the present study, rice husk procured from indigenous sources was thoroughly washed with water to remove the dust and dried at room temperature for a day. Colour of washed rice husk changes from yellowish to black because of charring of organic matter. It was then heated to 600 ° C for 12 h to remove the carbonaceous material when the colour changes from black to grayish white. The silica-rich ash, thus obtained, was used as a filler material in the preparation of composites. SEM analysis of rice husk particles shown in Figure-7 & Figure-8 and Chemical composition of the rice husk ash after the above treatments is shown in Table-1.

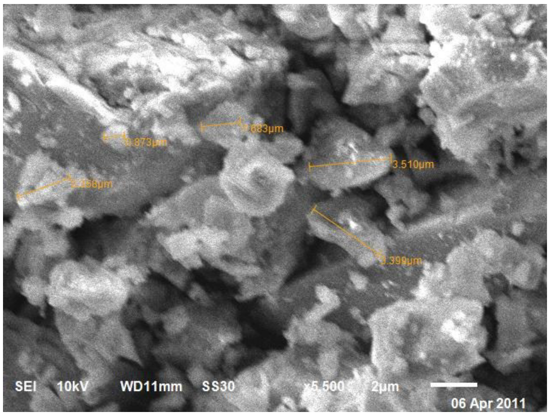

Figure-7: SEM image of NRHA after milling

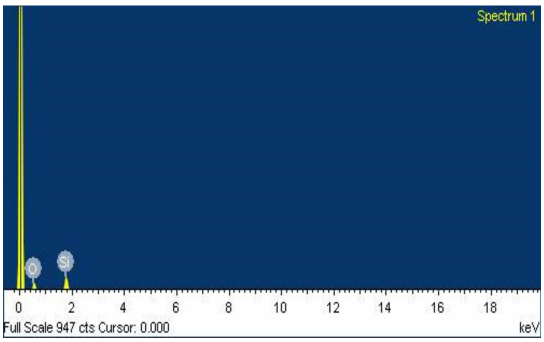

Figure-8: SEM-EDX spectrum of A356.2/RHA composites

Table 1: ChemicalcompositionofRHA

Constituent	%
Silica – SiO_2	91.21
Alumina – Al_2O_3	3.52
Carbon	1.23
Calcium Oxide – CaO	1.59
Magnesium Oxide – MgO	0.52
Potassium Oxide – KaO	0.38
Ferric Oxide – Fe_2O_3	0.22

Preparation of nanocomposite

The reason is reinforcements are in the nanometer size and it is extremely difficult to disperse them uniformly in liquid metals because of their poor wettability in metal matrix and their large surface to volume ratio, which easily induces agglomeration and clustering. It is desirable to produce as cast light weight components of MMNCs with good reinforcement distribution and structural integrity. Furnace with ultra sonicator setup has shown in figure-9.

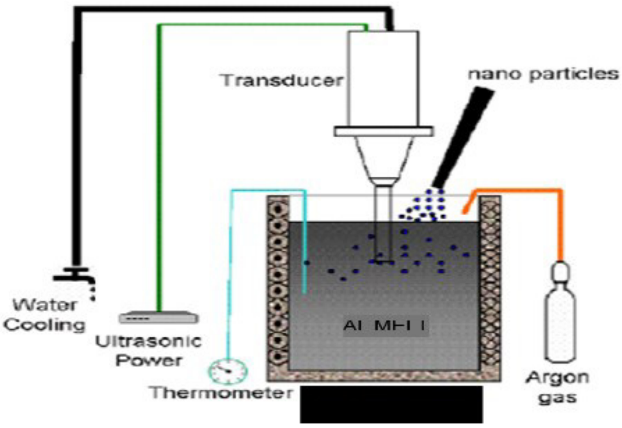

Figure-9: proposed model is used for disperse the nanoparticle in MMC

Conclusion

Conventional milling machine is converted as CNC milling and best suited for friction stir welding. Synthesis of rice hush ash nanoparticles is prepared by high energy ball mill and characterized by SEM. The good dispersed nanoparticles are possible with ultra sonicator. Weld bead characteristics are studied along with the weld strength in feature.

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